ECSE 354 – Electromagnetic wave propagation

LAB 2 WEEK 1 – Theory – Thevenin equivalent and propagation velocity

OBJECTIVE – Propagation velocity

Upon completion of this unit, you will know how to measure the velocity of propagation of a signal in a transmission line, using the step response method. Based on the measurements, you will know how to determine the relative permittivity of the dielectric material used to construct this line.

Velocity of Propagation

A radio signal travels in free space at the velocity of light (approximately 3.0×10^8 m/s). In a transmission line, a signal will travel at a relatively lower speed. This is due mainly to the presence of the dielectric material used to construct the line. In fact, the velocity of propagation of a signal in a transmission line, v_P, is dependent upon the distributed inductance and capacitance of the line, L' and C' (see Figure 1.14). The equation for calculating v_P is:

$$V_P = \frac{1}{\sqrt{L'C'}}$$

where

v_P = Velocity of propagation (m/s);

L' = Distributed inductance, in henrys per unit length (H/m);

C' = Distributed capacitance, in farads per unit length (F/m)

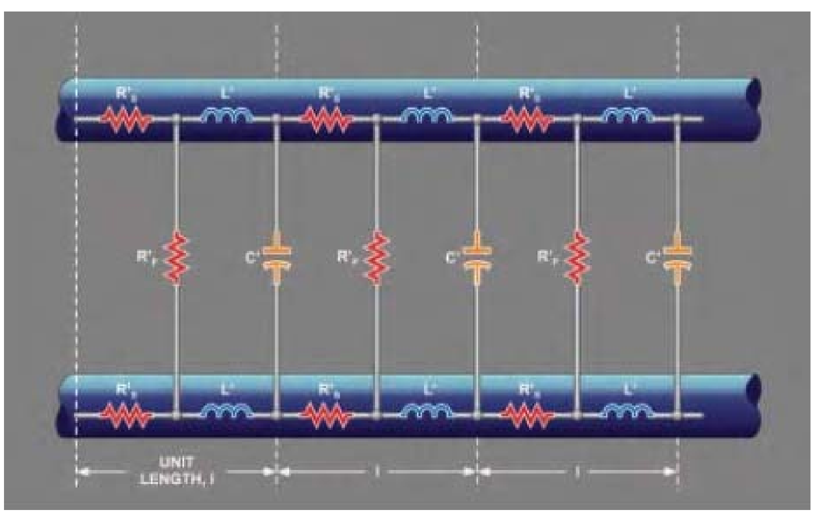

Figure 1-34. Equivalent circuit of a two-conductor transmission line.

Step (Transient) Response Method

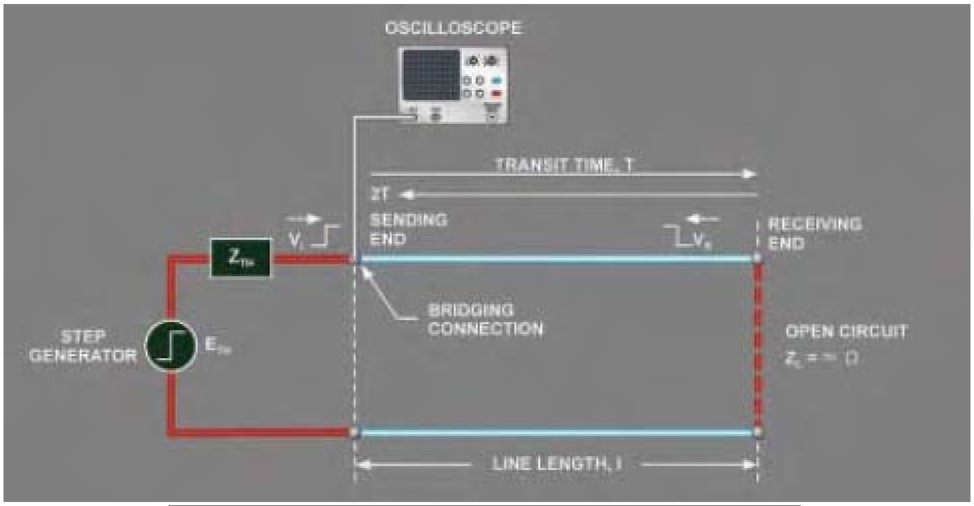

Figure 1.15: Measuring the velocity of propagation of a signal by using the step response method.

The velocity of propagation of a signal in a transmission line can be measured by using the step response method. This method requires that a step generator and a high-impedance oscilloscope probe be both connected to the sending end of the line, using a bridging connection, as Figure 1.15 shows. The receiving end of the line is left unconnected [impedance of the load in the open-circuit condition ($\propto \Omega$)]

The signal propagation through the line is described below (refer to Figure 1.15).

- At time t = 0, the step generator launches a fast-rising, positive-going voltage, V_I, into the line. The rising edge of V_I is called a step, or transient. This step is incident because it comes from the generator and is going to travel down the line toward a possibly reflecting load.
- Incident step V_I propagates at a certain velocity, v_P, along the line. It arrives at the receiving end of the line after a certain transit time, T. There its level has decreased by a certain amount due to the resistance of the line.
- Since the impedance of the load at the receiving end of the line is in the open-circuit condition ($\propto \Omega$), it does not match the characteristic impedance of the line. This impedance mismatch causes the incident step to be reflected back toward the generator. The reflected step, V_R, gets back to the step generator after a time equal to twice the transit time, 2T. 2T is synonymous with round-trip time, or back-and-forth trip time.

The signal at the sending end of the line, as a function of time, is the step response signal. As Figure 1-36 shows, this signal is the algebraic sum of the incident step V_I and reflected step V_R. Step V_R is superimposed on step V_I, and is separated by a time 2T from the rising edge of V_I.

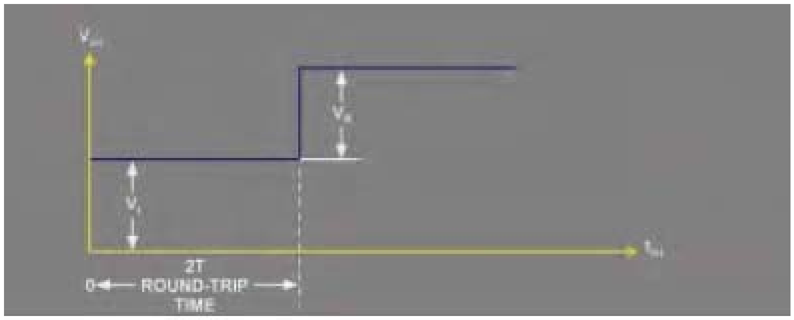

Figure 1.16: Voltage at the sending end of the open-circuit line (step response signal)

By measuring time 2T on the oscilloscope screen, the velocity of propagation of a signal in a transmission line, v_P, can be determined, using the formula below.

$$v_P = \frac{2l}{2T}$$

Where,

v_p = Velocity of propagation (m/s or ft/s);

l = Length of the line (m or ft);

2T = Round-trip time, i.e. time taken for the launched step to travel from the generator to the line receiving end and back again to the generator (s).

Transmission lines that are lossy, and whose series losses are predominant, will appear as a simple RC network (resistor-capacitor network) for a short time following the launching of a voltage step, as Figure 1.17 shows. This is due to the high frequency components contained in the voltage step.

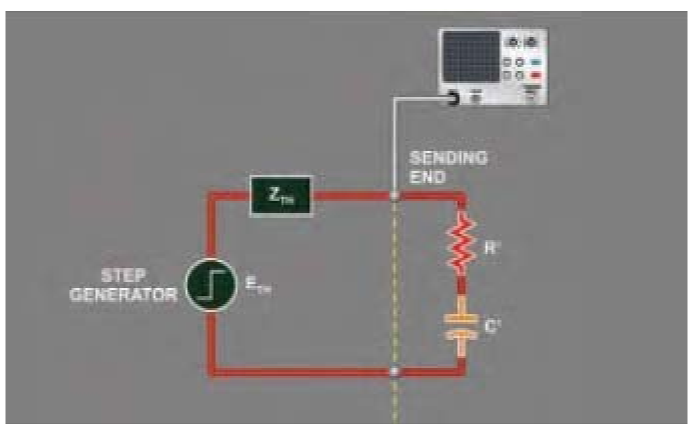

Figure 1.17: Lossy line with predominant series losses

The time constant, τ, of the RC network (not to be confused with the transit time T) is determined by constants R_s and C, which are themselves derived from the distributed series resistance, R'_s, series inductance, L', and parallel capacitance, C', of the line. Consequently, the time constant of the RC network is independent of the length of the line.

In that case, the incident and reflected steps observed at the sending end of the line will first rise to a certain level, and then increase exponentially at a rate determined by the time constant of the RC network, as Figure 1.18 shows. This does not prevent the measurement of time 2T on the oscilloscope screen for calculation of the velocity of propagation. However, it is clear that lossy lines cause a degradation in the rise time of voltage steps.

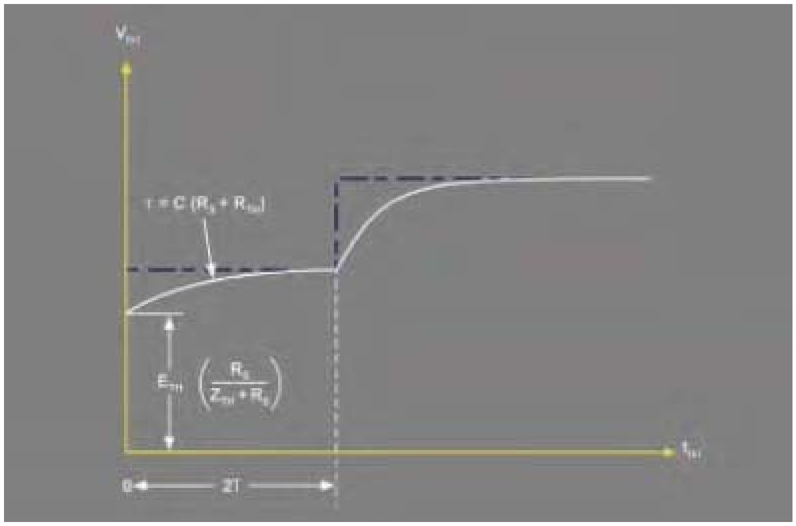

Figure 1.18: Incident and reflected steps at the sending end of a lossy line with predominant series losses.

Velocity Factor

The velocity of propagation of a signal in a transmission line is usually expressed as a percentage of the velocity of light in free space. This percentage is called the velocity factor, V_F. For example, a transmission line with a V_F of 66% will transmit signals at about 66% of the velocity of light.

$$V_F = \frac{v_p}{c} \times 100\%$$

where

V_F = Velocity factor (%);

v_P = Velocity of propagation in the transmission line (m/s or ft/s);

c = Velocity of light in free space (about 3.0×10^8 m/s).

TRANSMISSION LINES A and B of the circuit board are RG-174 coaxial cables. Consequently, they have a theoretical velocity factor, V_F, of 66%.

Relative Permittivity (Dielectric Constant)

The velocity of propagation of a signal in a transmission line is determined mainly by the permittivity of the dielectric material used to construct the line. Permittivity is a measure of the ability of the dielectric material to maintain a difference in electrical charge over a given distance.

The permittivity of a particular dielectric material is normally expressed in relation to that of vacuum. This ratio is called relative permittivity, or dielectric constant. When the velocity of propagation in a transmission line is known, the relative permittivity of the dielectric material used to construct that line, ϵ_r, can be determined by using the equation below.

$$\varepsilon_r = \frac{c^2}{v_P^2}$$

Where

ϵ_r = Relative permittivity (dielectric constant);

c = Velocity of light in free space (3.0×10^8 m/s, or 9.8×10^8 ft/s);

V_P = Velocity of propagation (m/s or ft/m).

The formula for calculating relative permittivity indicates that a higher velocity of propagation indicates a lower relative permittivity, since the velocity of light is a constant value.

MATERIAL	RELATIVE PERMITTIVITY, ϵ_r	VELOCITY FACTOR, V_F(%)
Vacuum	1.00000	100
Air	1.0006	99.97
Teflon	2.10	69.0
Polyethylene	2.27	66.4
Polystyrene	2.50	63.2
Polyvinyl chloride	3.30	55.0
Nylon	4.90	45.2

Table 1-1. Relative dielectric constant of various materials.